

A STUDY OF CERTAIN FINELY DIVIDED METALS  
AND A METHOD FOR THEIR PREPARATION

DISSERTATION

SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF  
THE JOHNS HOPKINS UNIVERSITY IN CONFORMITY  
WITH REQUIREMENTS FOR THE DEGREE OF  
DOCTOR OF PHILOSOPHY

BY  
EARL G. INSLEY

BALTIMORE  
1932

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## A STUDY OF CERTAIN FINELY DIVIDED METALS AND A METHOD FOR THEIR PREPARATION<sup>1</sup>

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*Received August 30, 1934*

### INTRODUCTION

More than a century ago attention was directed to the phenomenon of adsorption as an explanation for the phenomenon of catalysis, and the unsaturated forces at solid surfaces were believed to be the real origin of both phenomena. During recent years an intensive study has brought to light the close connection in many cases between catalysis and the specific nature of adsorption (8). In marked contrast to inert adsorbents, metallic catalysts seem to have a definite saturation capacity for certain gases. In the case of the adsorption of hydrogen on nickel this saturation capacity is reached at low pressures (2).

It has been shown that the activity of a catalyst and its adsorptive capacity are greatly affected by the method of its preparation. As it is practically impossible to prepare two catalysts which are exactly alike, it seems very important that adsorption measurements and a study of catalytic activity be made on the same catalyst under the same conditions.

The first work of this nature is that of Pease (5), who has studied the catalytic combination of ethylene and hydrogen on copper by measuring the reaction rate and the adsorption isotherms of the reactants and the product, using the same catalyst for all the measurements. Since then there has been very little work of this kind, although there have been numerous investigations of the adsorption of various gases by several metals which presumably were active catalysts. The metals, which have been used commonly, have been prepared by reducing their oxides with hydrogen.

Metals may be prepared from their amalgams by distilling off the mercury but, so far as the writer is aware, no investigation of the catalytic activity of finely divided metals prepared in this way has been undertaken. Preliminary experiments had shown that metals prepared from the amal-

<sup>1</sup> From the dissertation submitted by E. G. Insley to the Faculty of Philosophy of The Johns Hopkins University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy, June, 1932.

gams are active catalysts; therefore it seemed that it would be interesting to study metals prepared in this way.

The hydrogenation of ethylene was selected as the reaction to investigate in connection with these catalysts, and for several reasons. It is a simple reaction, with no side reactions, and it goes to completion. The reactants and the product are reasonably stable, and the course of the reaction may be followed conveniently by measuring the decrease in pressure, the volume remaining constant.

According to Sabatier (6), the hydrogenation of ethylene occurs at the surface of nickel, cobalt, copper, and iron at temperatures about 150°C. Recently it has been shown that this reaction takes place at a readily measurable rate at 0°C. It was decided to measure the velocity of this reaction at 0°C., and to determine the adsorption isotherms of hydrogen, ethylene, and ethane at 0°C. on each of the above metallic catalysts prepared from their amalgams. Furthermore it seemed that it would be interesting to compare the catalysts prepared from the amalgams with those prepared from the oxides. Accordingly metallic catalysts, prepared by reducing the oxides with hydrogen, were studied in the same manner and under the same conditions as those prepared from the amalgams.

After completing the work outlined above it was decided to measure the adsorption of hydrogen on nickel at higher temperatures.

#### APPARATUS AND EXPERIMENTAL PROCEDURE

The adsorption apparatus (figure 1) was a modified form of the type of apparatus used by Bennett (1) in the adsorption of carbon dioxide on oxide catalysts. The manifold of the apparatus was connected through a mercury cut-off and a trap to a mercury vapor pump, which was backed by a Hyvac oil pump. The trap was at all times immersed in a bath of solid carbon dioxide and alcohol. The manometers and the cut-off were connected through traps to leveling bulbs. The mercury used for these had been purified by acid washing and distilling in the usual manner.

The bulb B, used to measure the hydrogen admitted to the catalyst, was calibrated, surrounded by a water jacket, and sealed in the system so that it could be connected either to the hydrogen reservoir or to the catalyst in bulb A. A three-way stopcock S was inserted so that gases other than hydrogen could be admitted from a gas buret.

#### *Materials*

Recrystallized Baker's c. p. salts were used as the source of the metals. The mercury used in forming the amalgams was prepared by decomposing Baker's c. p. mercuric oxide. The hydrogen used in these experiments was prepared by electrolyzing a 15 per cent solution of sodium hydroxide between nickel electrodes. It was passed through a trap surrounded by



solid carbon dioxide to remove most of the water carried over from the generator, then over glowing platinized asbestos to remove traces of oxygen, and finally through a long spiral immersed in liquid air to remove traces of water. It was stored in a 2-liter balloon flask. The ethylene was the compressed gas prepared especially for anesthesia by the Kansas City Oxygen Gas Company of Baltimore. The ethane was obtained from the Matheson Company of East Rutherford, N. J. Both the ethylene and ethane were passed through a long U-tube surrounded by solid carbon dioxide to remove any condensible material. Each of these gases was admitted to the catalyst by means of a water-jacketed gas buret.

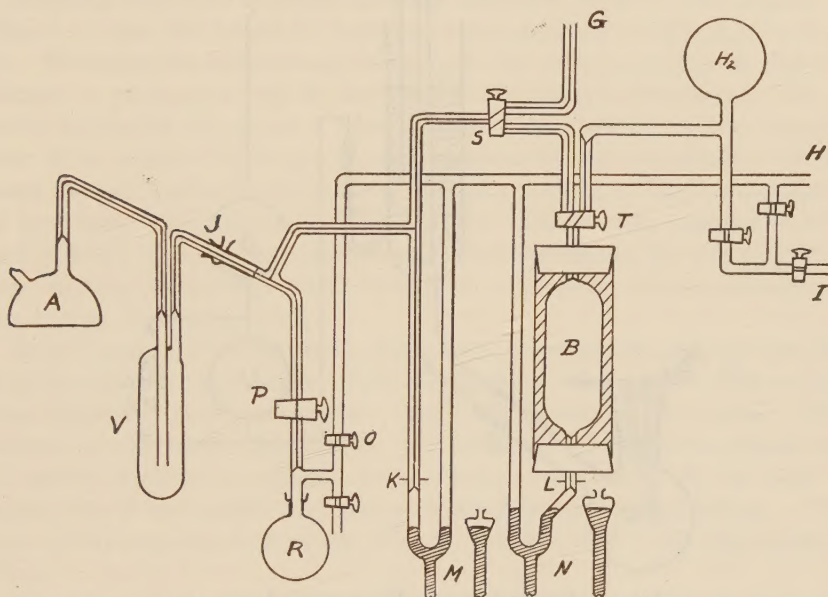


FIG. 1. ADSORPTION APPARATUS

G, to gas buret; H, to high vacuum; I, to hydrogen generator

The metals studied were iron, cobalt, nickel, and copper. Each metal was prepared both from the oxide and the amalgam. The metals prepared from the oxides are referred to as No. 2. Metals referred to by other numbers were prepared from the amalgams. The oxides were reduced in the adsorption bulb by hydrogen for twenty-four hours at the following temperatures: copper No. 2, 200°C.; cobalt No. 2, 390°C.; iron No. 2, 390°C.; nickel No. 2, 275°C.

The amalgams were prepared essentially according to the method given in Smith's *Electrochemistry* for the electrolytic determination of metals using a mercury cathode. About 10 cc. of mercury was put in the cell and connected by a platinum wire in the side arm to the negative side of a

14-volt D. C. line. A solution of the sulfate of the metal, acidified with sulfuric acid, was added to the cell (figure 2), and a platinum anode was then suspended in the solution. In the case of cobalt, iron, and nickel the double ammonium sulfates were used. After the amalgam had been formed, the current was left on, the solution siphoned out, and the amalgam washed with distilled water. Then the amalgam was transferred to the adsorption bulb in the presence of oxygen-free nitrogen, the inlet sealed, and the system evacuated.

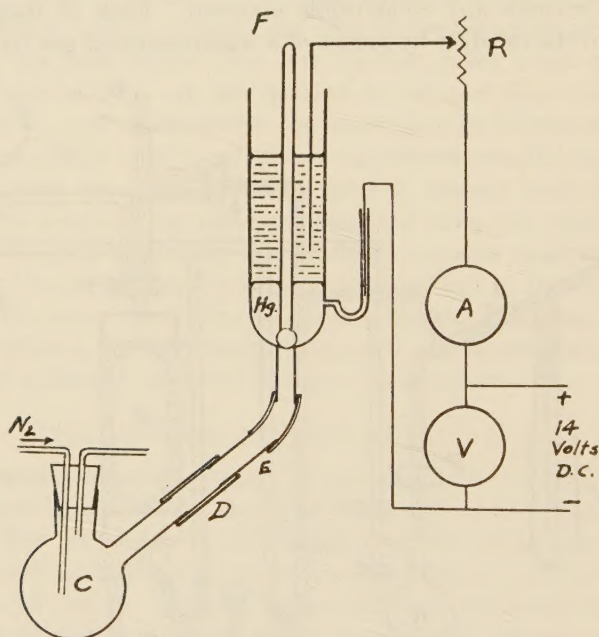


FIG. 2. APPARATUS FOR PREPARING AMALGAM

By means of valve *F* the amalgam is run into bulb *C*. Then, closing gum tubing *D* and removing glass tubing *E*, the amalgam is transferred to bulb *A* of the adsorption system. The amalgam is protected by oxygen-free nitrogen.

The capillary tube leading from bulb *A* (figure 1) was electrically heated by nichrome wire, an electric furnace was placed about bulb *A*, and the mercury was distilled into trap *V*. When practically all the mercury had distilled over, the bulb and trap were rotated as a unit about joint *J* as an axis; the mercury ran down into bulb *R*. In this way it was possible to remove the mercury from the adsorption system without breaking the vacuum. The last traces of mercury were removed by immersing the trap *V* in a bath of solid carbon dioxide and ether, and heating the metals to the following temperatures: copper No. 1, 170°C.; cobalt No. 1, 185°C.; iron No. 1, 220°C.; nickels No. 1, 3, and 4, 170°C.; nickel No. 5, 170°C. The



evacuation was continued until the pressure became as low as  $1 \times 10^{-5}$  to  $1 \times 10^{-6}$  mm.

*Calibration and method of adsorption measurements*

With the adsorption bulb empty, the apparatus was evacuated and bulb A was immersed in a bath of finely shaved ice and distilled water. In all experiments the trap V (figure 1) was immersed to the same depth in a bath of solid carbon dioxide and ether. The temperature, as shown by a pentane thermometer, was  $-81^{\circ}\text{C}$ . and was kept very nearly constant by adding small quantities of solid carbon dioxide from time to time.

Keeping stopcock P closed and the mercury level in manometer M (figure 1) near the height K, hydrogen was admitted to bulb A from bulb B. Knowing the temperature of the gas, the volume of bulb B, and the change in pressure in bulb B, the volume of hydrogen admitted to bulb A could be readily calculated. After adjusting the mercury level in manometer M to exactly the height K, the pressure M was measured. In the same manner a number of pressures M, corresponding to various quantities of hydrogen, were measured. When these volumes were reduced to  $0^{\circ}\text{C}$ . and 760 mm. pressure and plotted against the pressures, M, a straight line was obtained from which could be read the calibration volume corresponding to any desired pressure.

In an adsorption measurement the volume of gas admitted to the catalyst was corrected for the volume of gas displaced by the metal. This volume was calculated from the known weight and density of the metal. This method of calibration was used by Nikitin (4) in a study of the adsorption of carbon dioxide on metallic iron, cobalt, and nickel. In the case of nickel No. 5 the system was also calibrated using purified helium. The two calibrations checked within 0.01 cc., which is within the experimental error.

After the catalyst had been prepared and evacuated as described above, a small quantity of hydrogen was admitted to the catalyst, the pressure M was measured, and the volume reduced to standard conditions as described in connection with the calibration above. Then by subtracting from this reduced volume the volume of gas required to give the same pressure in the calibration of the system, the volume of gas adsorbed is obtained. By making a series of pressure measurements, M, corresponding to increasing amounts of gas, the adsorption isotherm could be readily determined.

The adsorption at  $0^{\circ}\text{C}$ . of hydrogen, ethylene, and ethane on each metal was measured. In each case, immediately after determining the adsorption of hydrogen on the metal, ethylene was admitted to the catalyst in an amount approximately equal to that of the hydrogen present. Then the rate of hydrogenation was obtained by measuring the rate of decrease in pressure in the system. After evacuating the catalyst, the adsorption of

ethylene was measured, and similarly the adsorption of ethane was measured. Before each adsorption measurement, the catalyst was outgassed in the same manner as was used to prepare the metal for the adsorption of hydrogen. In the case of nickels No. 4 and 5 only the adsorption of hydrogen was studied.

In preparing nickel No. 5 the amalgam was evacuated before being heated. After driving off the mercury, the adsorption of hydrogen on the metal was measured at 0°C. Then the nickel was evacuated at 100°C. and the adsorption and desorption of hydrogen at 99.6°C. was measured. Then the metal was evacuated and the adsorption at 0°C. redetermined. After the system had apparently reached equilibrium the bulb containing the metal was slowly heated, keeping the same amount of hydrogen in the system, and pressure measurements were taken at various temperatures up to 150°C. At each of several different points the temperature was kept constant, and pressure measurements were taken until the system had apparently reached equilibrium.

#### EXPERIMENTAL RESULTS

The larger part of the results will be presented graphically and the corresponding tables omitted. A brief description of the results, obtained from each metal studied, will be given.

*Copper.* Neither of the catalysts adsorbed a measurable quantity of any of the gases. Copper No. 2 catalyzed the hydrogenation of ethylene at a readily measurable rate (figure 3), but copper No. 1 was completely inactive.

*Cobalt.* Cobalt No. 2 showed a much higher adsorption of all the gases (figure 4), but both catalysts were equally effective in catalyzing the reaction (figure 5).

*Iron.* The quantities of gases adsorbed by both catalysts were small (figure 6), the adsorption of ethylene on iron No. 2 being the largest. Iron No. 2 was a much better catalyst for the reaction than iron No. 1 (figure 7).

*Nickel.* No nickel catalyst prepared from the amalgam adsorbed a measurable amount of any of the gases. Nickel No. 2 adsorbed a comparatively large quantity of hydrogen and ethylene (figure 8). As is shown in figure 9, nickels No. 1, 2, and 3 displayed the same activity in catalyzing the hydrogenation of ethylene.

Nickel No. 5 adsorbed a large amount of hydrogen at 99.6°C. as is shown in figure 10. When the adsorption at 0°C. was repeated it was found to be very small. Keeping the hydrogen, which was admitted at 0°C., in the system and slowly heating the catalyst, it was found that the pressure began to decrease between 50° and 60°C. The measurements at a series of temperatures between -80° and 150°C. are given in table 1 in the order in which they were obtained.



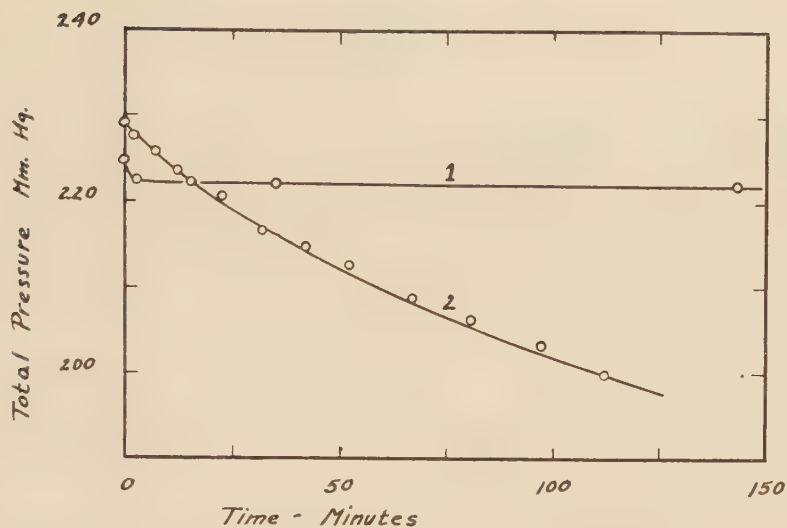


FIG. 3. HYDROGENATION OF ETHYLENE BY COPPER CATALYSTS  
Curve 1, copper No. 1 from the amalgam; Curve 2, copper No. 2 from the oxide

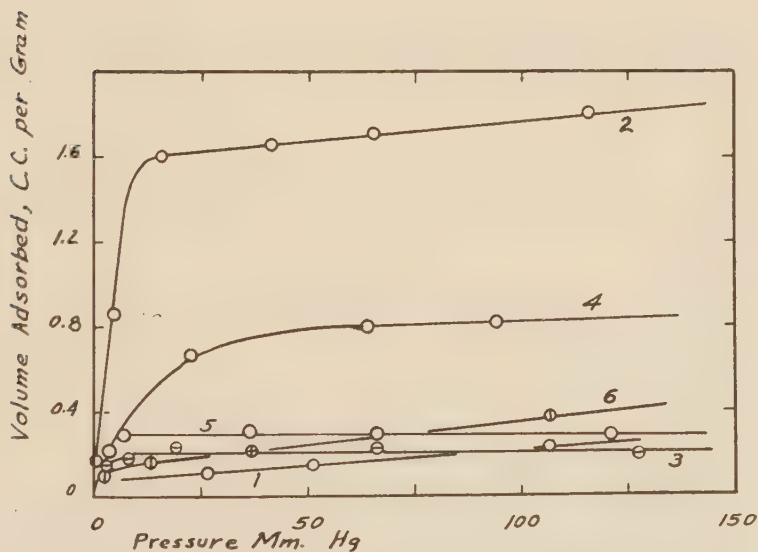


FIG. 4. ADSORPTION BY COBALT CATALYSTS

Cobalt No. 1 prepared from the amalgam; cobalt No. 2 prepared from the oxide.  
1, hydrogen on cobalt No. 1; 2, hydrogen on cobalt No. 2; 3, ethylene on cobalt No. 1; 4, ethylene on cobalt No. 2; 5, ethane on cobalt No. 1; 6, ethane on cobalt No. 2.

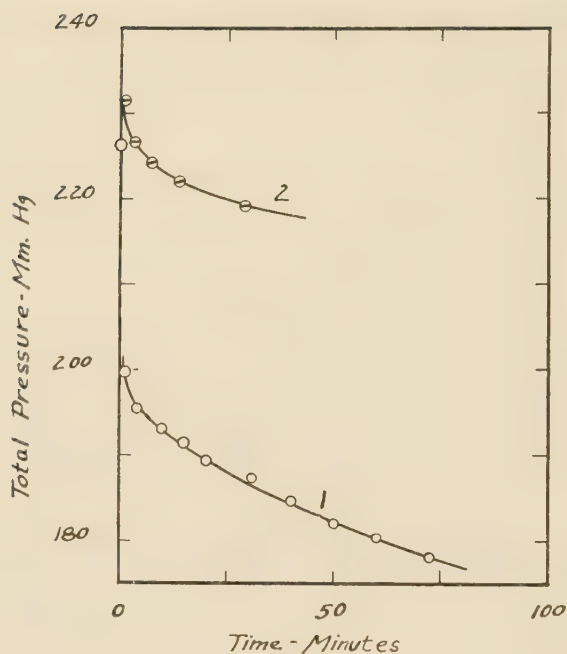


FIG. 5. HYDROGENATION OF ETHYLENE BY COBALT CATALYSTS  
1, cobalt No. 1 from the amalgam; 2, cobalt No. 2 from the oxide

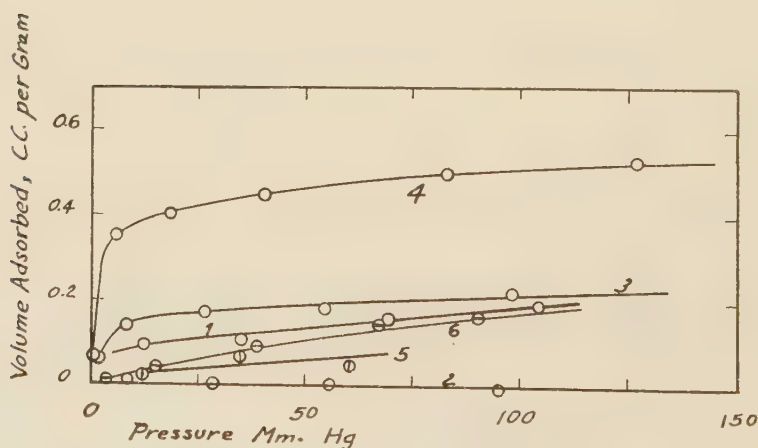


FIG. 6. ADSORPTION BY IRON CATALYSTS

Iron No. 1 from the amalgam; iron No. 2 from the oxide. 1, hydrogen on iron No. 1; 2, hydrogen on iron No. 2; 3, ethylene on iron No. 1; 4, ethylene on iron No. 2; 5, ethane on iron No. 1; 6, ethane on iron No. 2.



## DISCUSSION

*Adsorption and reaction rates at 0°C.*

The adsorption of hydrogen, ethylene, and ethane on the catalysts was in general of the same nature as found by other workers. In the case of the copper catalysts, prepared from both the amalgam and the oxide, and the several nickel catalysts, prepared from the amalgams, the adsorption of the gases was much too small to be accurately measurable. In the case of

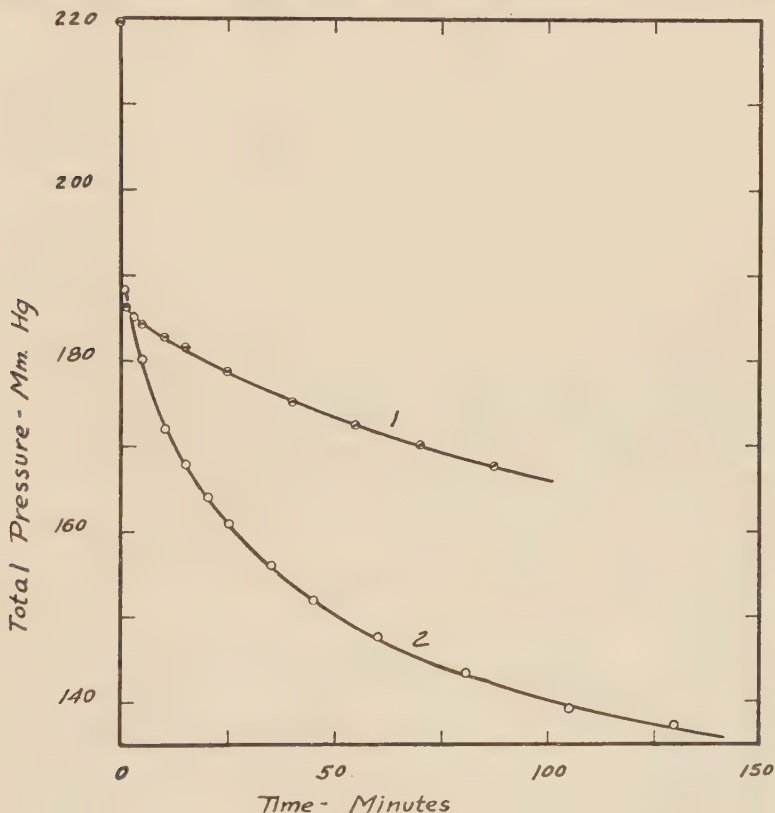


FIG. 7. HYDROGENATION OF ETHYLENE BY IRON CATALYSTS  
1, iron No. 1 from the amalgam; 2, iron No. 2 from the oxide

the other metals studied the amounts of hydrogen and ethylene adsorbed became practically independent of the pressure at fairly low pressures. The amount of ethane adsorbed was approximately proportional to the pressure.

All the metals studied, with the exception of copper No. 1, catalyzed the hydrogenation of ethylene at 0°C. at a readily measurable rate. Copper No. 1 gave practically no reaction even on standing as long as twenty-four

hours. This is consistent with the results of Pease (5), who found that mercury poisoned a copper catalyst so that the hydrogenation of ethylene proceeded very slowly and that this poisoning effect was permanent. It

TABLE 1  
*Adsorption of hydrogen on nickel no. 5*

| NO. | TEMPERATURE | VOLUME ADSORBED<br>(0°C., 760 mm.) | PRESSURE |
|-----|-------------|------------------------------------|----------|
|     | °C.         | cc.                                | mm.      |
| 1   | 0.0         | 0.02                               | 20.2     |
| 2   | 72.4        | 3.15                               | 0.0      |
| 3   | 72.4        | 3.40                               | 19.9     |
| 4   | 99.5        | 4.04                               | 15.7     |
| 5   | 150.0       | 4.06                               | 16.2     |
| 6   | 0.0         | 4.22                               | 12.3     |
| 7   | 0.0         | 4.23                               | 12.4     |
| 8   | -80.0       | 4.30                               | 10.0     |
| 9   | 99.5        | 4.16                               | 14.6     |
| 10  | 150.0       | 4.06                               | 16.2     |
| 11  | 150.0       | 4.13                               | 57.3     |

Equilibrium had not been reached when measurements No. 3 and 4 were taken. Between readings 6 and 7 the catalyst was kept at room temperature (26°C.) for twenty-six hours. No. 8, no change in adsorption on standing five hours. No. 10, no change in adsorption on standing ten hours. More hydrogen was admitted between Nos. 2 and 3 and between Nos. 10 and 11.

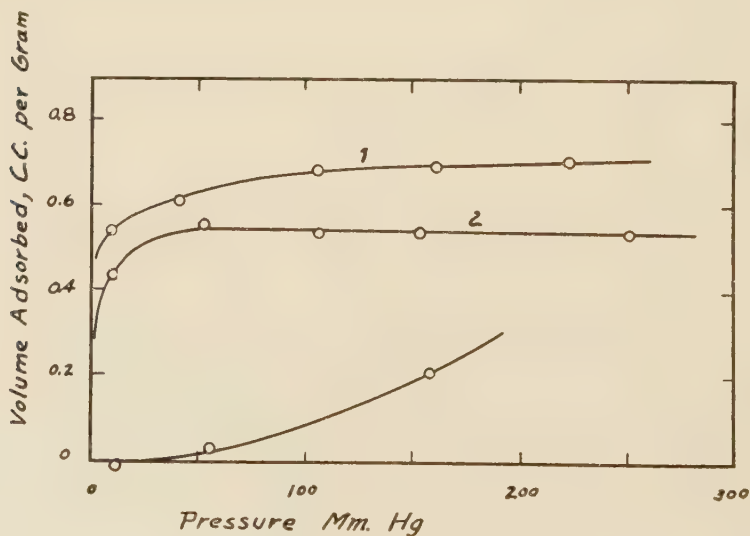


FIG. 8. ADSORPTION BY NICKEL CATALYSTS

Adsorption by nickels No. 1 and 3 (from the amalgam) negligibly small. Adsorption by nickel No. 2 (from the oxide): 1, hydrogen; 2, ethylene; 3, ethane.



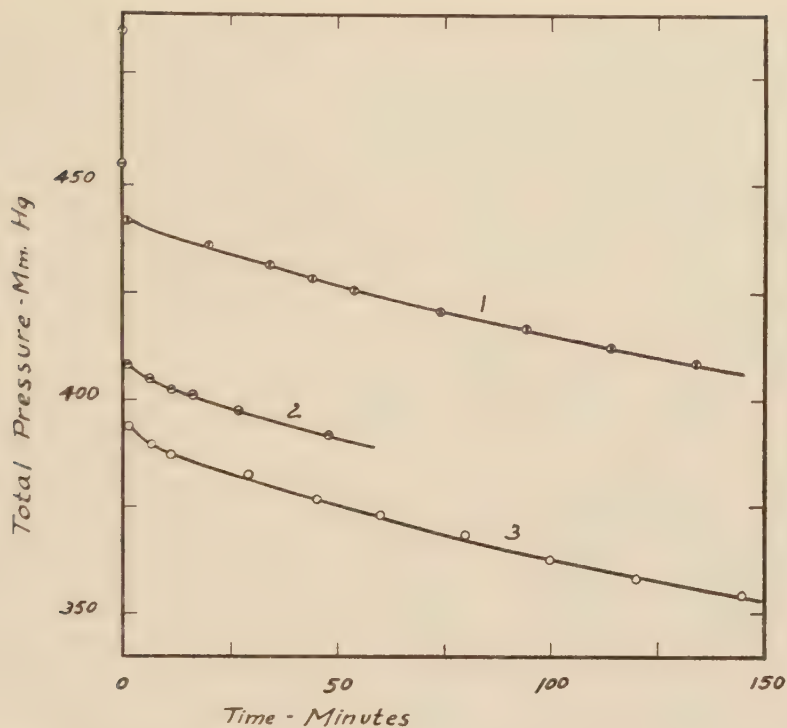


FIG. 9. HYDROGENATION OF ETHYLENE BY NICKEL CATALYSTS

1, nickel No. 1 from the amalgam; 2, nickel No. 3 from the amalgam; 3, nickel No. 2 from the oxide.

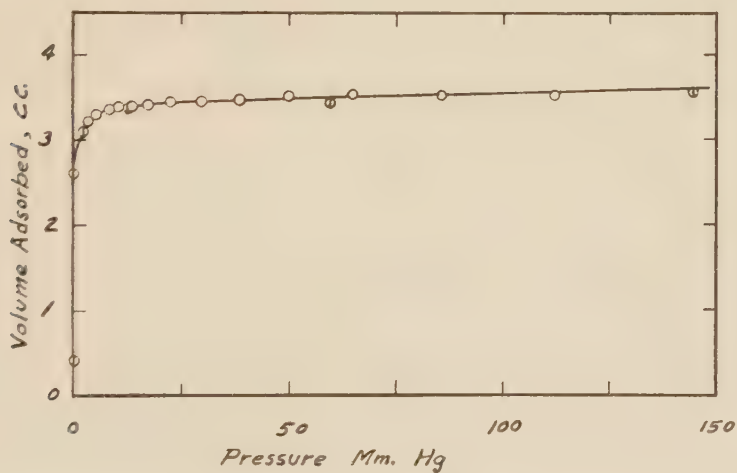


FIG. 10. ADSORPTION OF HYDROGEN ON NICKEL NO. 5 (FROM THE AMALGAM) AT 99.6°C.

⊕, adsorption; ○ desorption

seems that mercury has the effect of destroying the active spots on the catalyst; thus it is not surprising that copper No. 1, prepared from the amalgam, is not an active catalyst. This poisoning effect of mercury was not noticeable in the study of the other metals.

The rate of hydrogenation of ethylene by nickel (figure 9), was the same for the catalysts prepared by the two methods. Both cobalt catalysts (figure 5) gave equally rapid rates of reaction. As nickel and cobalt prepared from the oxides showed much higher adsorption of hydrogen and ethylene than the same metals prepared from the amalgams, it is evident that high adsorption of reactants does not necessarily mean a correspondingly high activity as a catalyst.

The change in total pressure was taken as a measure of the rate of reaction. In the case of iron, nickel, and cobalt from the amalgams, the initial pressures for the reaction rates were calculated from the known volumes of hydrogen and ethylene present and the amounts of the two gases adsorbed. As the quantities of the two gases adsorbed were quite small, it seems that the calculated initial pressures should be fairly accurate. The initial pressures thus calculated are in each of the above-mentioned cases 40 to 60 mm. higher than the first experimentally determined pressure. It is apparent that the initial rate of reaction is very high, for the large decrease in total pressure from its initial value (calculated) to the first experimental value is much too great to be attributed to adsorption, even though the adsorption of the reactants were very high, which is not the case.

Pease (5), in a study of this catalytic reaction, found that when the concentration of hydrogen was kept constant the speed of the reaction decreased as the concentration of ethylene increased. He also found that the deactivation of a copper catalyst by heat treatment or by poisoning resulted in a much larger decrease in the adsorption of hydrogen than of ethylene. This seems to indicate that the adsorption of hydrogen is the more important factor in the hydrogenation of ethylene.

In view of these results an explanation may be offered for the above-mentioned behavior. In all experiments in which the rate of hydrogenation was measured, the adsorption of hydrogen was measured first and then, leaving the hydrogen on the catalyst, an equal volume of ethylene was admitted. Thus at the very first part of the reaction the hydrogen was in large excess. As the ethylene diffused into the catalyst the two gases were competing for the free spaces on the catalyst surface. It seems only reasonable to assume that the amount of hydrogen adsorbed was much greater at the beginning of the reaction than after the gases had become thoroughly mixed. As the reaction rate seems to depend primarily on the amount of hydrogen adsorbed, it seems quite in order that the reaction should be much more rapid at the beginning than after a considerable amount of the adsorbed hydrogen had been displaced by the ethylene.

The above explanation is in agreement with the results of Harker (3), who investigated this same reaction on a supported copper catalyst and found that hydrogen left on the catalyst overnight greatly increased the initial speed of the reaction, while ethylene similarly left on the catalyst greatly reduced the initial speed of the reaction. As Harker has pointed out, the ethylene probably slows down the reaction rate by impeding the movement of adsorbed hydrogen on the catalyst surface to the active centers where the reaction presumably takes place.

*The adsorption of hydrogen on nickel at temperatures from  $-80^{\circ}$  to  $150^{\circ}\text{C}$ .*

The adsorption of hydrogen on nickel No. 5 (amalgam) at  $99.6^{\circ}\text{C}$ . is very high as compared with the negligibly small adsorption at  $0^{\circ}\text{C}$ . The isotherm (figure 10) shows the adsorption to be completely reversible with respect to pressure.

As is shown by table 1, practically no hydrogen was adsorbed by nickel No. 5 at  $0^{\circ}\text{C}$ ., but on slowly heating the catalyst a considerable adsorption began to occur at about  $50^{\circ}\text{C}$ . The adsorption at these temperatures was quite slow; at  $72.4^{\circ}\text{C}$ . more than two hours were required for the system to come to apparent equilibrium. The rate of adsorption seemed to increase with rising temperature. At  $100^{\circ}\text{C}$ . the time necessary to reach apparent equilibrium was less than one hour.

The amount of hydrogen adsorbed was less at  $150^{\circ}\text{C}$ . than at  $100^{\circ}\text{C}$ ., and on cooling the catalyst it was found that the amount of adsorbed gas increased steadily down to  $-80^{\circ}\text{C}$ . The increase (0.24 cc.) was small in comparison to the total amount adsorbed. On again heating the catalyst the same amount of adsorption was found for each temperature as had been observed at the same temperature in the previous measurement.

From these results it appears that the hydrogen is taken up by the nickel in two ways. The first is ordinary "physical adsorption," which decreases with rising temperature. Numerous measurements had shown the amount of hydrogen adsorbed at  $0^{\circ}\text{C}$ . on this and other nickel catalysts prepared from the amalgam was very small. It was apparent therefore that the amount of "physical adsorption" at  $100^{\circ}$  to  $150^{\circ}\text{C}$ . was extremely small and practically negligible. The amount of gas taken up in the second manner seems to remain remarkably constant over the range of temperatures studied. The change in adsorption from  $-80^{\circ}$  to  $150^{\circ}\text{C}$ . can be ascribed to the change in the "physical adsorption."

The second manner of "sorption" could be explained by Taylor's (7) theory of "activated adsorption," or by a solution of the gas in the metal or possibly a combination of the two. The time required for the process is in agreement with either explanation. The adsorption isotherm at  $100^{\circ}\text{C}$ . is of the same shape as would be expected on the basis of activated adsorption. However, according to Ward (9), a solution isotherm may have the



same form as an adsorption isotherm. The present experimental results do not seem to warrant an attempt to exclude either of these explanations.

#### SUMMARY

1. The adsorption of hydrogen, ethylene, and ethane has been studied on metallic catalysts prepared from both the oxides and the amalgams.
2. The rate of the hydrogenation of ethylene has been studied on the same catalysts under the same conditions as above.
3. The metals prepared from the amalgams showed a catalytic activity which is quite comparable to that of the metals prepared from the oxides.
4. A very high initial rate of reaction has been found and an explanation has been offered for the same.
5. The adsorption of hydrogen on nickel has been studied at temperatures from  $-80^{\circ}$  to  $150^{\circ}\text{C}$ . It has been shown that only a very small part of the total adsorption is due to "physical adsorption."

#### REFERENCES

- (1) BENNETT, O. G.: Dissertation, The Johns Hopkins University, 1930.
- (2) GAUGER AND TAYLOR: *J. Am. Chem. Soc.* **45**, 920 (1923).
- (3) HARKER, G.: *J. Soc. Chem. Ind.* **51**, 323T (1932).
- (4) NIKITIN: *Z. anorg. allgem. Chem.* **154**, 130 (1926).
- (5) PEASE, R. N.: *J. Am. Chem. Soc.*, **45**, 1196 (1923).
- (6) SABATIER-REID: *Catalysis in Organic Chemistry*. D. Van Nostrand Co., New York (1923).
- (7) TAYLOR: *J. Am. Chem. Soc.* **53**, 578 (1931).
- (8) TAYLOR AND BURNS: *J. Am. Chem. Soc.* **43**, 1273 (1921).
- (9) WARD: *Trans. Faraday Soc.* **28**, 399 (1932).

## BIOGRAPHY

The author of this dissertation, Earl G. Insley, was born August 10, 1907 at Bivalve, Maryland. He received his early education in the public schools of Wicomico County, Maryland. He was graduated from the Wicomico High School in June 1924, and entered the School of Engineering of The Johns Hopkins University in October 1924. He received the degree of Bachelor of Science in Chemistry in June 1928. In 1928, he was admitted to the School of Higher Studies of the Faculty of Philosophy as a graduate student in Chemistry. During the years 1928-1929 and 1929-1930, he was a student assistant in Chemistry. He held a University Scholarship, 1930-1931, and was an instructor in Chemistry, 1931-1932.







